Leap Seconds

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Definition of Seconds

- Rotational Second
  - 1 / 86,400 of mean solar day
- Ephemeris Second
  - First used in 1956
  - 1/31,556,925.9747 of tropical year 1900
  - Length of year based on 19th century astronomical observations

Atomic Second

- SI second: 9,192,631,770 periods of the radiation corresponding to the transition between 2 hyperfine levels of the ground state of the Cesium 133 atom (adopted 1964)
- Realizes the Ephemeris Second
- Frequency based on lunar observations from1954.25 to 1958.25

SI second preserves the rotational second of mid-nineteenth century

Time Scales

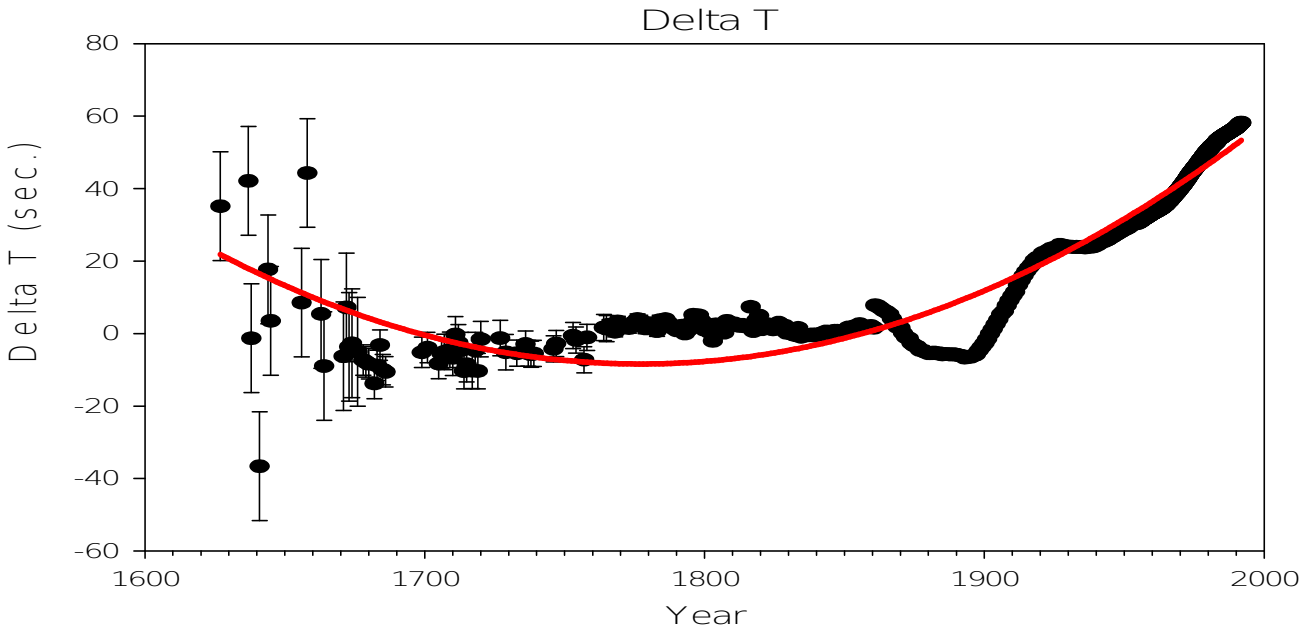
- Rotational
  - UT1 is modern realization of historical astronomical time scales including
    - Mean Solar Time
    - Greenwich Mean Time
    - Greenwich Civil Time
    - Universal Time (without suffixes)
    - Weltzeit

Time Scales (continued)

- Atomic
  - TAI (International Atomic Time)
    - Follow-on from
      - A.1 (maintained at USNO with input from 9 other laboratories originally. - now only USNO)
      - AM (at BIH with input from many laboratories)
      - A3
        - at BIH with input from 3 best laboratories
        - became AT (or TA) in 1969, TAI in 1971
      - others
    - All atomic time scales were made equal to UT1 corrected for seasonal effects on 1 Jan 1958 0h 0m 0s
    - may be considered modern realization of Ephemeris Time (offset in epoch)

Earth Rotation

- Well documented deceleration
  - Tidal
  - Change in figure

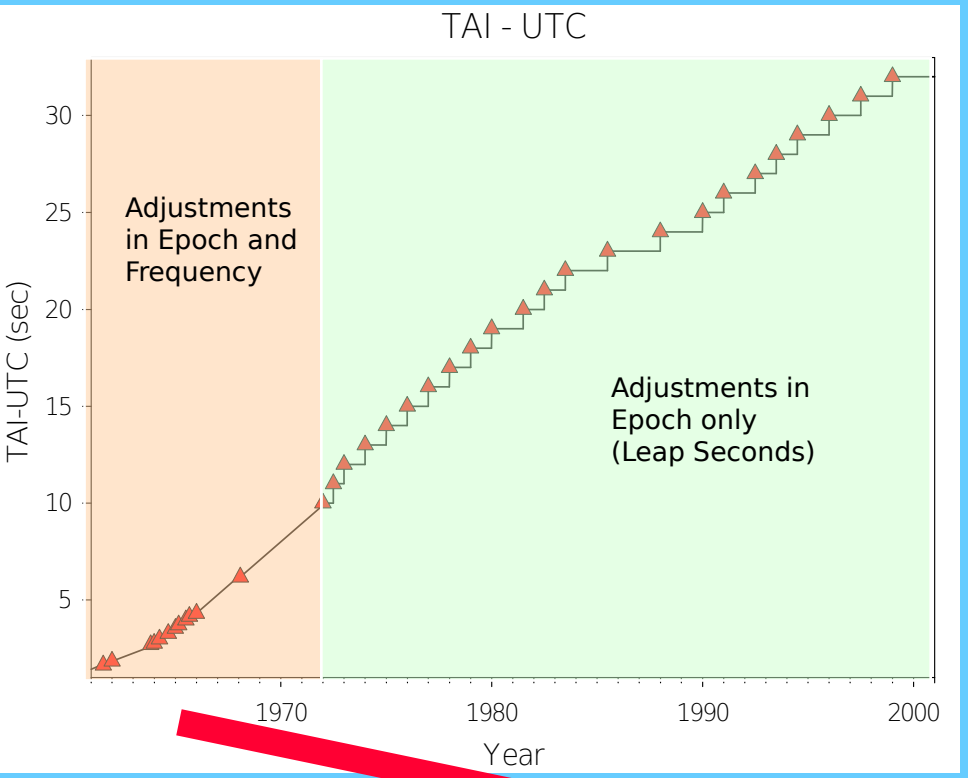


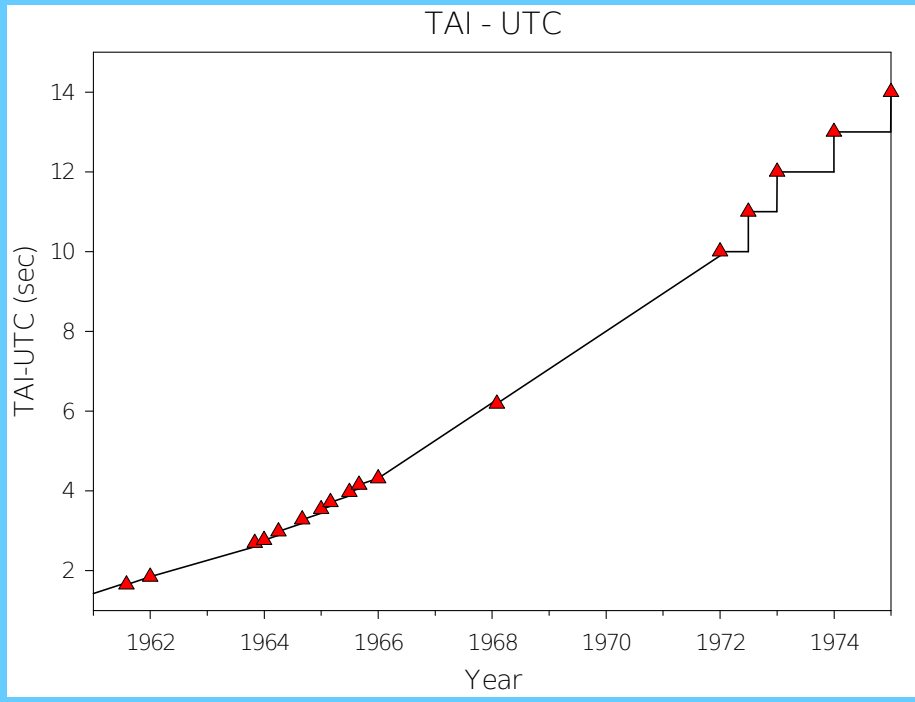
Historical Answers

- UTC (Coordinated Universal Time)
  - Begun in 1960 as cooperative effort of U.S. Naval Observatory and Royal Greenwich Observatory to make coordinated changes to clocks
  - in 1965 BIH defined UTC with respect to atomic time
  - Epoch and frequency adjusted to match UT1 corrected for seasonal variations
- Current UTC adopted beginning in 1972
  - no changes in frequency
  - leap seconds so that |UTC-UT1| < 0.9 s

UTC consistent with previous definitions of legal time

TAI-UTC


TAI - UTC
TAI-UTC (sec)
30
25
20
15
10
5
Adjustments in Epoch and Frequency
Adjustments in Epoch only (Leap Seconds)
1970
1980
1990
2000
Year


TAI - UTC
TAI-UTC (sec)
14
12
10
8
6
4
2
1962
1964
1966
1968
1970
1972
1974
Year

Causes for Concern

- Frequency of leap seconds increasing
  - Increasing public annoyance
- Software issues
  - Unpredictable
  - Continuous second counts: days with 86,401 seconds
  - Time stamping 23h 59m 60s
- Communications problems
  - coordination of events during a leap second
- Growth of systems based on independent time scales

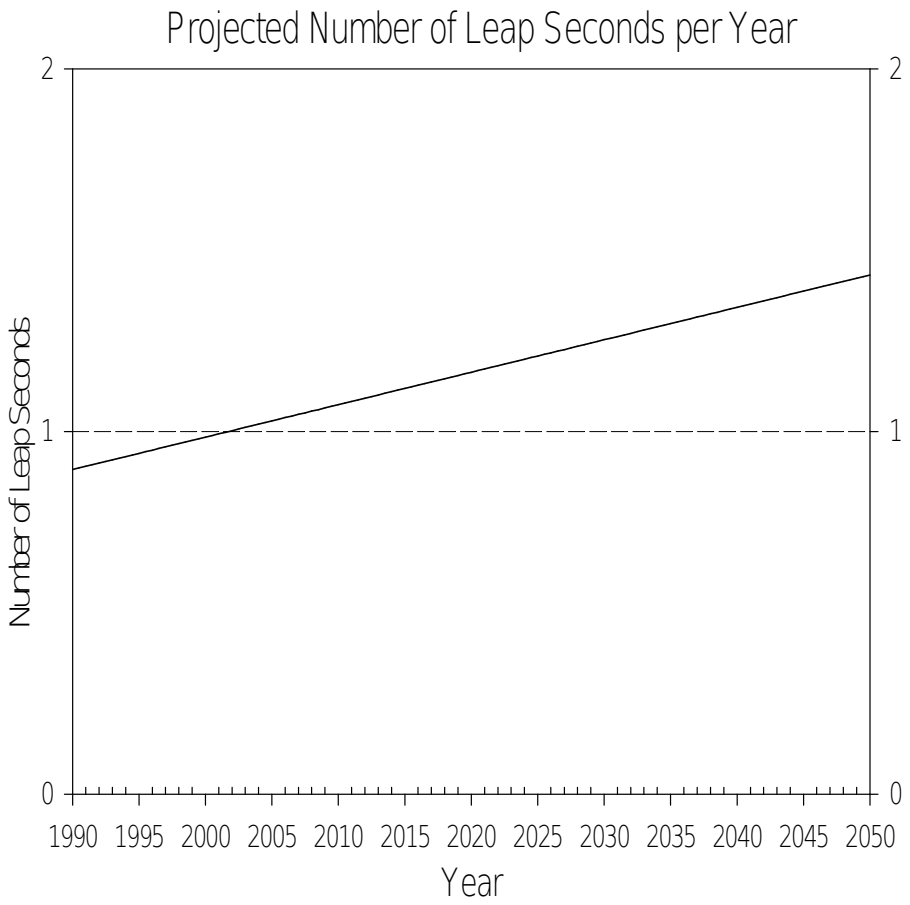
Things to Consider

- Navigation
  - 1 second = 1/4 mile at the equator
- Computer software
  - Continuous second counts? 61-second minute?
- Communications
  - Maintain synchronization over the leap second?
- Legal definitions
  - Mean solar time?
- Religious observances
  - Sunrise, noon, sunset?

Options

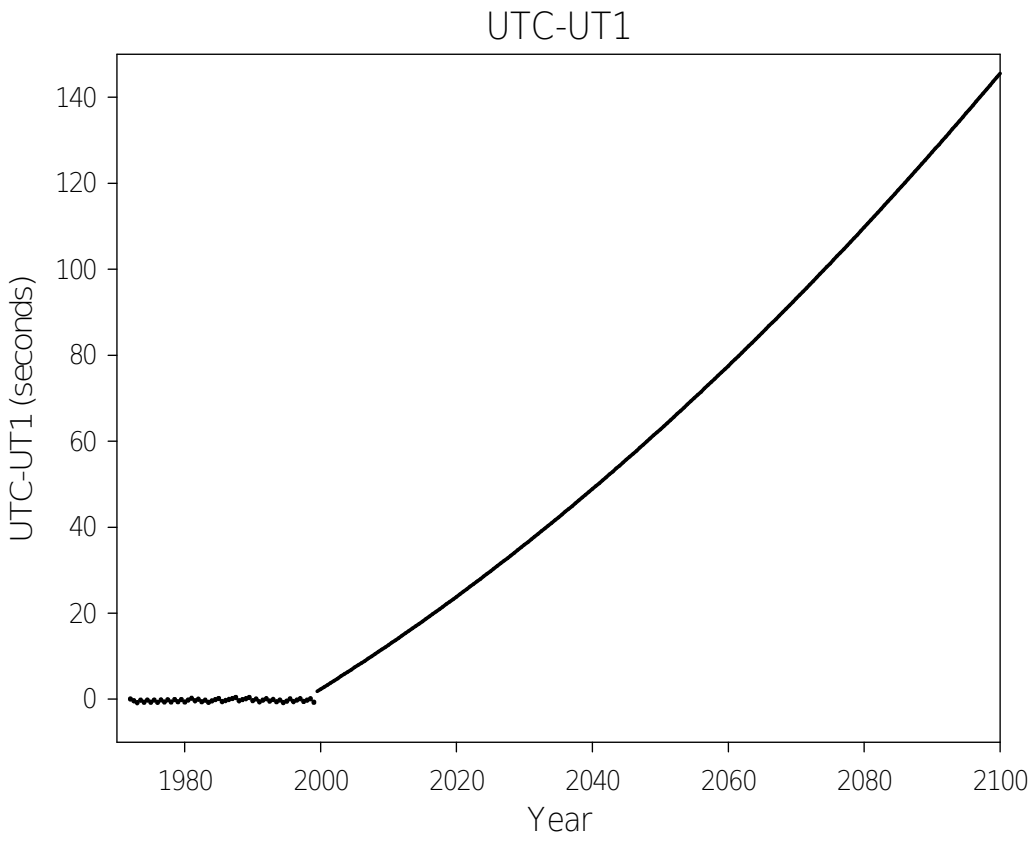
- Status quo
- Discontinue leap seconds
- Use TAI
- Re-define second
- Increase tolerance for |UTC-UT1|
- Smooth over the leap second step
- Predictable periodic adjustment of UTC
- Conventional adjustment of UTC
  - Every leap year? Every 10 years?
  - Predict leap seconds based on deceleration model

Status Quo


Projected Number of Leap Seconds per Year
Number of Leap Seconds
0
1
2
1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
Year

- **Pro:**
  - No changes required
  - Minimize concerns of celestial navigators
- **Con:**
  - Frequency of leap seconds increasing
  - Communications, software problems
  - Growth of systems based on independent time scales

Discontinue Leap Seconds



- **Pro:**
  - Eliminate causes for concern
- **Con:**
  - Unlimited growth of |UTC-UT1|
  - Legal definitions of time?

Use TAI

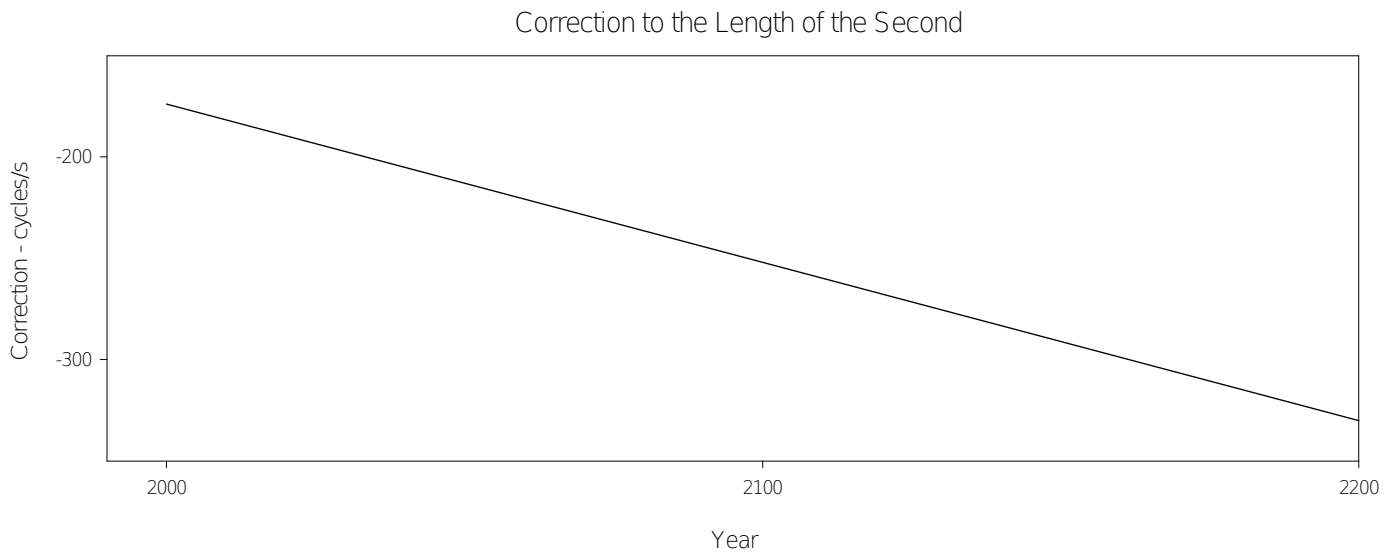
- Similar to elimination of leap seconds
- TAI must be more accessible

- **Pro:**
  - Eliminate causes for concern

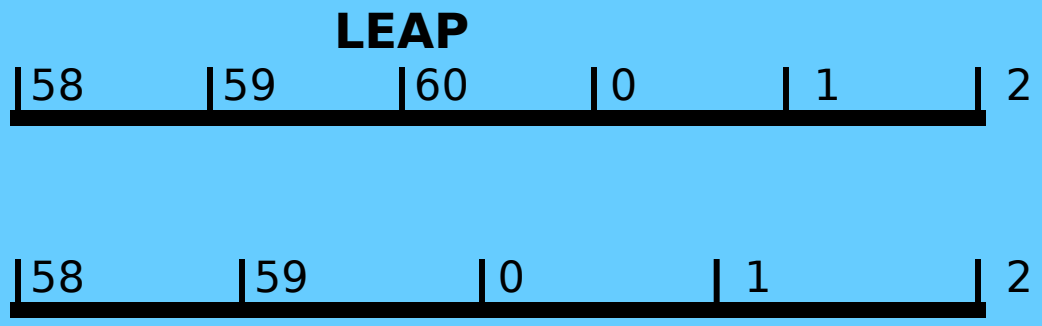
- **Con:**
  - TAI must be more accessible
  - Legal definitions of time?

Redefine the Second

- **Pro**
  - Fundamental Solution
- **Con**
  - Require redefinition of physical units
  - Temporary solution



Smooth Over Leap Second Step



- **Pro**
  - Eliminates the “extra” second
- **Con**
  - Requires seconds of different lengths
  - Date of adjustment unpredictable
  - Implementation?

Increase Tolerance for |UTC-UT1|

- **Pro**
  - Easy to accomplish
- **Con**
  - Larger discontinuities
  - DUT1 code limitations
  - Date of adjustment unpredictable
  - What is an acceptable limit?

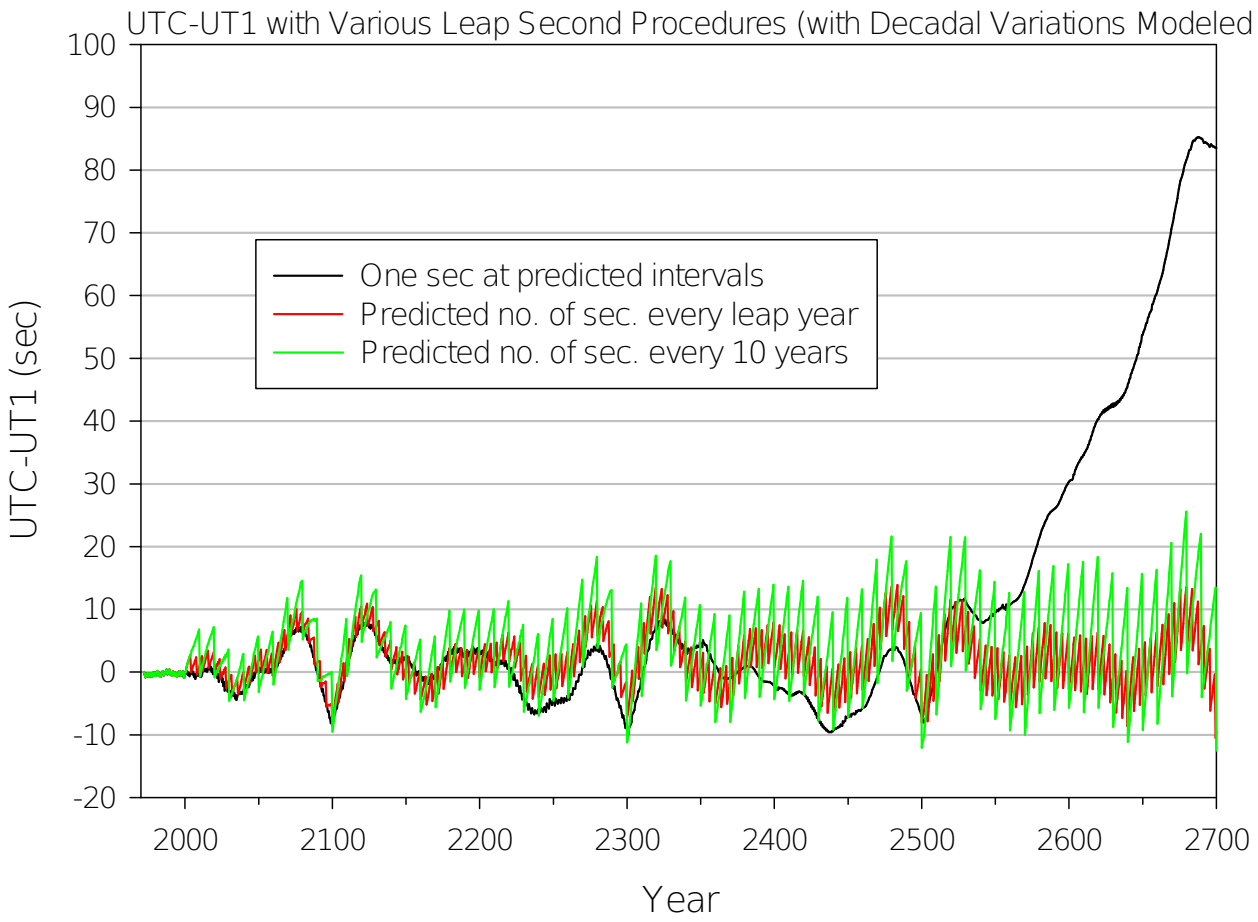
Periodic Adjustment of UTC

- Pro
  - Date of adjustment is predictable
- Con
  - Number of leap seconds remains unpredictable
  - Large discontinuities

Conventional Adjustment of UTC

- Unknown number of leap seconds at predictable intervals
  - **Pro**
    - Date of adjustment is predictable
  - **Con**
    - Number of leap seconds remains unpredictable
    - Large discontinuities possible
    - |UTC-UT1|>>1
- Known number of leap seconds at predictable intervals
  - **Pro**
    - Date of adjustment and number of leap seconds predictable
  - **Con**
    - Large discontinuities possible
    - |UTC-UT1|>>1

Conventional Adjustment of UTC



What to do?

- Question needs study
  - URSI
  - IAU
  - ITU-R